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Resonant Bits: Harmonic Interaction with Virtual Pendulums

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ABSTRACT

This paper presents the concept of *Resonant Bits*, an interaction technique for encouraging engaging, slow and skilful interaction with tangible, mobile and ubiquitous devices. The technique is based on the resonant excitation of harmonic oscillators and allows the exploration of a number of novel types of tangible interaction including: *ideomotor control*, where subliminal micro-movements accumulate over time to produce a visible outcome; *indirect tangible interaction*, where a number of devices can be controlled simultaneously through an intermediary object such as a table; and *slow interaction*, with meditative and repetitive gestures being used for control.

The Resonant Bits concept is tested as an interaction method in a study where participants resonate with virtual pendulums on a mobile device. The Harmonic Tuner, a resonance-based music player, is presented as a simple example of using resonant bits. Overall, our ambition in proposing the *Resonant Bits* concept is to promote skilful, engaging and ultimately rewarding forms of interaction with tangible devices that takes time and patience to learn and master.

Author Keywords

Human-Computer Interaction; Tangible User Interface; Ideomotor Control; Slow Technology; Resonance.

ACM Classification Keywords

H.5.2. User Interfaces: Interaction Styles

INTRODUCTION

Resonant Bits aims to bridge the 'divide between the worlds of bits and atoms' [9] by using resonance as a metaphor that spans both domains. We propose that this technique offers a number of novel methods of interacting with tangible interfaces including ideomotor control, indirect interaction and slow interaction.

The inspiration for developing an interaction technique around resonance arose from our experience investigating the ideomotor response [10] while developing new technology for stage magic. In particular we explored the effect that occurs when a participant holding a pendulum is asked to will it to move purely through the power of the mind. In many cases the pendulum will start to swing and will actually follow the participant's command. Perhaps counter-intuitively, even when the physical nature of the effect is explained (as the resonant amplification of many micro-movements of the fingers holding the string) the feeling of directly controlling the pendulum by thought alone persists. We envisage that an advanced resonance-based system will be able to recreate this effect for use in tangible interaction.

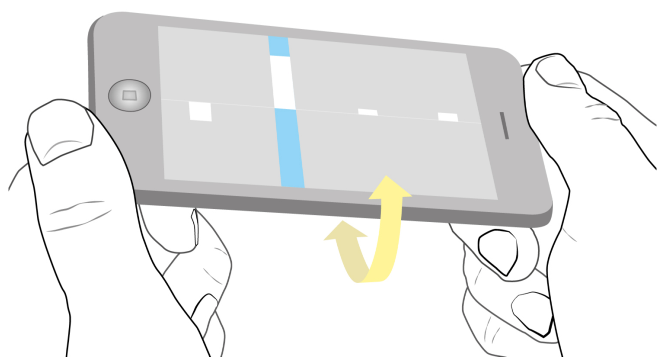

Figure 1. Resonating with virtual pendulums. Rocking the phone at the same frequency as one of the pendulums will gradually increase the pendulum's amplitude.

To test the feasibility of using resonance as an interaction technique we developed a mobile device application based on interaction with virtual pendulums. The procedure of evaluating the Resonant Bits concept is not straight-forward, as the goals are not the typical HCI criteria of efficiency, speed, or reduced mental workload, and the goals we wish to achieve (slowness, engagement, skilful interaction) require longitudinal study which we will conduct in future work. In this paper, our initial study aims to verify whether the Resonant Bits concept will work as an input technique. In particular, can people after a brief period of familiarisation physically resonate with a digital bit?

RELATED WORK

The Resonant Bits concept has been developed as a method for informing the design of new Tangible User Interfaces [9] in particular with the aim of moving 'from data centred to perceptual-motor centred' tangible interaction [3]. This move promotes the development of rich and tightly coupled interactions with tangibles that encourage the 'challenge and pride that comes with acquiring and possessing motor skills' [2]. In particular, Resonant Bits supports new methods of exploring affordance and 'feedforward' [14] in tangible interaction, by revealing to the user partial outcomes of an action before it is completed.

The Resonant Bits concept is based on the ideomotor response which occurs when a person unconsciously makes micro-movements to achieve a goal. When the point is reached that these micro-movements are near-invisible to both user and observer, then Resonant Bits may be used as a platform for exploring 'magical interaction'. Using magic as a metaphor may later on help to inform future Resonant Bits designs, helping users build mental models of 'rationally impossible' interactions [13].

Resonant Bits explores how slowness can be encouraged during interaction. This form of slow, or 'time-aware', interaction has been likened to playing a musical instrument, in that the device encourages the stretching of the present moment. The difficulty in designing such a device is that it 'should not be technology that is tiresome and time consuming, but technology that stretches time and slows things down' [5]. We propose Resonant Bits as a potential method for achieving slow interaction in tangible interfaces and also a possible method of promoting 'flow' [1] when using a tangible interface.

There are a few existing interfaces and projects which share a similar approach to Resonant Bits. The technique of 'motion-pointing' allows the indirect selection of a target through the matching of the target's elliptical motion [4]. Shoogle [16] is an interface that allows the user to 'read' a mobile device through the active exploration of a physical model that represents data within the device. The ISH series of devices explore the concept of emotional resonance in tangible interfaces, looking at 'the ability of a product to evoke positive images, memories, and emotions, and to encourage a prolonged, subtle, or stimulating effect beyond the initial impact' [7]. It is proposed that this resonance with a device is reinforced by a 'fit between the product and the kind of interaction on the one hand, and a persons (latent) concerns, value system, personality, skills, senses' [6]. The possibility of using resonant agents controlled by sympathetic movement has been proposed as a method for 'continuous uncertain interaction' [15]. This work also includes the technique of dynamically changing the resonant frequency of each agent, thus forcing the user into closely following the changing resonance.

VIRTUAL PENDULUM STUDY

In order to test the basic feasibility of Resonant Bits as interaction technique we conducted a study determining whether novice users could intentionally isolate a single pendulum from multiple on screen. The study was also designed to collect general feedback on the Resonant Bits concept.

Virtual Pendulum Application

The application runs on a phone, presenting the user with a set of pendulums represented by a line of bars (Fig.2). Each pendulum has an individual frequency laid out in order from lowest to highest across the phone.

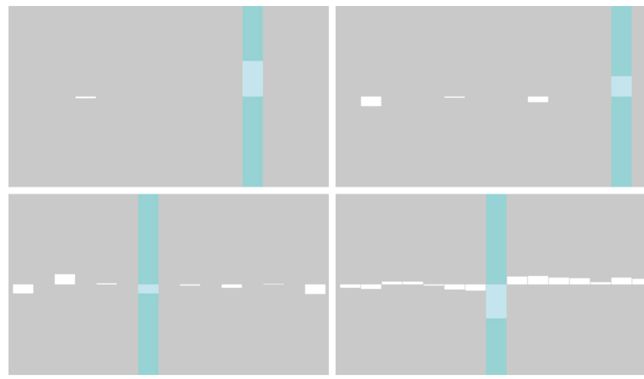

Figure 2. The four tasks from the user study with 2, 4, 8 and 15 pendulums. In each, the pendulum highlighted in blue is the target pendulum.

The physical model for each pendulum is a driven harmonic oscillator with velocity proportional damping. The damping value is chosen to provide an underdamped response so the mass oscillates around the centre point when disturbed. In this discrete model, the next position of the mass x_{n+1} is calculated from the sum of the force F_n, the returning force of the spring Ax_n and damping proportional to the velocity $B(x_{n-1} - x_n)$.

$$x_{n+1} = F_n - Ax_n + B(x_{n-1} - x_n)$$

The force value F is calculated from the differential of the phone's x-axis accelerometer, so that the constant of gravity is cancelled and only movement is registered. Use of the phone's gyroscope was trialled, but found to be less sensitive than the accelerometer. The maximum value of F is capped so that small movements provide the same value as large movements. The force value is scaled by a coefficient chosen to provide a level of influence on the model that can build up a resonant oscillation but without overpowering the returning force of the spring. The spring coefficient A is the primary influence on the dominant frequency of each oscillator and the values are chosen to span the frequency range of 0.5Hz to 4Hz.

Procedure

Twenty participants took part in the study. We asked a number of background questions to gain knowledge of their past experience with mobile devices. Most used touchscreen phones regularly, but most participants didn't use their phones often for games although they did play some form of computer games. Overall the participants gave a neutral response on being asked if they had a good sense of rhythm.

Each participant was introduced to the mechanics of the system with a test application that presented a single pendulum at a time. The participants were then presented with the main task of moving a single highlighted pendulum with multiple pendulums on screen. Four tasks were presented to the participant consisting of 15, 8, 4 and 2 pendulums on screen at a time. In each task, a single target pendulum is highlighted with a blue bar and the user is asked to maximise the 'swing height' of the highlighted pendulum. Each task (of 15, 8, 4, 2 pendulums) was presented to the participant 6 times, totalling 24 trials per participant with each trial lasting 10 seconds. Both the trial order and target pendulum were randomised. After the 24 trials were complete, the participant was asked to fill out a questionnaire and give general feedback.

Selection and Isolation Results

To measure the success of isolating one pendulum's movement, the maximum amplitude reached by each pendulum is observed over the 10 seconds of each trial. If the target pendulum had the largest maximum amplitude then a successful selection of that pendulum is counted. The first column of Table 1 shows the success of achieving maximum amplitude in each of the trial conditions. A second method of measuring the success of isolation is to measure how much energy is put into each pendulum. This can be achieved by integrating the position of the pendulum over each ten second period of the trial. These 'energy' values can then be compared, and if the largest is the target pendulum, this counts as a successful isolation (second column of Table 1). The findings indicate that using the maximum amplitude maximum energy offer very similar possibilities of successfully detecting the target pendulum. It also indicates that without much practice, participants had a better than average chance of picking out the correct pendulum in all of the four tasks.

Pendulums	Amp.	Energy	Amp.Ratio	Energy Ratio
2	77%	77%	3.46	4.91
4	63%	64%	1.63	2.08
8	41%	47%	1.00	1.12
15	29%	30%	0.77	0.77

Table 1. Success rate across all trials of making the target pendulum gain a higher maximum amplitude or energy value than any other pendulum. Ratio of the maximum amplitude and integral values between target pendulum and the highest non-target pendulum.

We then looked at the level of certainty at which maximum values were obtained. This was calculated by dividing the maximum value of the target pendulum by the maximum value found across the other pendulums, resulting in a ratio value (Table 1). A ratio of 1.00 indicates that the target pendulum has the same maximum amplitude as the highest of the non-target pendulums, a ratio of 2.00 indicates that the target pendulum achieved twice the maximum of the next highest pendulum. In this case the energy shows a stronger result than the maximum amplitude.

Oscillator Frequencies

The user study also tested the choice of frequencies for the dynamic models. Ideally each pendulum has the possibility of reaching the same maximum amplitude as the others when handled by a skilled operator. Though relatively flat across the middle frequencies, the lower frequencies (oscillators 1 & 2) reach a higher maximum and there is a peak in the higher frequencies at oscillator 13. The average maximum height across all the trials shows a trend towards higher amplitude at lower frequencies. This correlates with feedback from the survey that the higher frequencies were harder to resonate with and generally were more frustrating. Using the data from the study, a scaling value for each pendulum has been implemented, making each pendulum more equally weighted.

Questionnaire

Results for the participants ability to concentrate on the task was neutral with a lean towards agreement. Half of the participants agreed that they had lost track of time, which we took as an indicator they may have entered a state of flow during the task. The majority of participants responded with 'neutral' to feeling in control of the pendulums. The majority of people were neutral on the task being frustrating, however this question was commonly queried as being difficult to answer, as the participants were only frustrated with some of the tasks. This was elaborated in the comments section where many participants only felt frustrated with the higher frequency pendulums and in a couple of cases the frustration was seen in a positive manner, 'almost like a mini-game'. Six participants disagreed strongly with the statement that it was frustrating. Most people agreed to enjoying the task, with five strongly agreeing.

> *There seems to be a range in which I can control the task. For lower frequencies (say first half of the screen) I felt I was in control. Higher frequencies on the other hand, were really frustrating. I just kept shaking the phone! When in control, you quickly "feel the beat".*

Observations on Types of Interaction

From observing participants during the study and from informal testing, a number of interaction methods have been observed: *Excitation*, where the device is initially given a shake to observe the natural frequencies of the pendulums. *Damping* of a pendulum, where the swing of a pendulum is deliberately slowed. *Guiding* of one person by another to teach how to resonate with a pendulum. *Priming* of the interface, by getting the desired pendulum swinging so it is ready to hit the threshold when the user desires. *Topping Up*, with the user attending to the energy level of multiple oscillators. *Flicking* energy into the system. *Full body* rocking and swaying. These observations indicate some of potentially rich physical interactions that may develop when interacting with Resonant Bits.

HARMONIC TUNER

To explore an application of how Resonant Bits can be used in practice, a simple music player inspired by Bottles [8] was created. In the Bottles project, sounds were *contained* in the bottles and uncorking lets the sound out. In Harmonic Tuner the sounds are contained in the resonant bits and are released by sympathetic excitation. Multiple permutations of the Harmonic Tuner have been explored. The most basic has three music tracks being represented by three resonant bits of different frequencies, with faster music mapped to the faster frequency oscillators. Another version plays musical notes, having a second set of oscillators laid out at right angles to the first set but using the same set of frequencies. This allows the user to select between bits with the same frequency by changing the axis of rocking. Two oscillators can then be played at the same time through a circular tilting motion.

Initial work has been made into incorporating dynamic damping into the Harmonic Tuner, so as the device is moved less the damping coefficient is decreased. This has the effect of penalising large movements and guides the user towards the micro-movements necessary for ideomotor control. Informal testing of this prototype indicates that the 'spooky' feeling of ideomotor control can occasionally be achieved. This experience may be enhanced further by using the strategies of 'misdirecting attention and setting false expectations' [12], in the case of the Harmonic Tuner, perhaps setting a second diversionary task, allowing the resonant gesture to be disguised within a larger movement.

CONCLUSION AND FUTURE WORK

This paper has proposed the concept of Resonant Bits as an interaction technique for tangible interaction, and the study has shown that it is feasible for a simple selection task even with complete novices. Although this first exploration of the Resonant Bits concept has been carried out on phones and tablets, we intend to extend this work by creating new Tangible User Interfaces specifically designed to support resonant interaction. One area in particular for further exploration is how the movement used to control a resonant bit can be transmitted *through* an intermediary object such as shelf, table or floor to allow indirect tangible interaction.

Further work on the Harmonic Tuner will investigate the addition of haptic feedback and also continuous sound feedback, an approach that has been shown to aid the learning of new tangible control mechanisms [11]. Currently the Harmonic Tuner only operates with pre-determined resonant bits with fixed frequencies and content, further work will explore methods to create new resonant bits 'on the fly' through oscillatory input. More complex dynamic models that involve for instance circular motion will also be investigated.

We hope that further work on the Resonant Bits concept will result in a range of physically engaging tangible interfaces that require the development of nuanced motor skills, which in turn may reward the user of such devices with immediate satisfaction and long term enjoyment.

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